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quasi-stationary motion in a straight line. The general equation is here published for the first time:

$$\begin{aligned}
 F_x &= \frac{e^2 \ddot{f}_x}{6\pi a c^2 (1-\beta^2)^{3/2}} - \frac{e^2 \mathbf{f} \cdot \boldsymbol{\beta} \dot{f}_x}{2\pi c^4 (1-\beta^2)^3} \dots - \frac{e^2 \dot{f}_x}{6\pi c^3 (1-\beta^2)^2} \\
 &\quad + \frac{e^2 \ddot{f}_x a}{9\pi c^4 (1-\beta^2)^{5/2}} - \frac{e^2 \ddot{f}_x a^2}{18\pi c^5 (1-\beta^2)^3} \dots \\
 F_y &= \frac{e^2 \ddot{f}_y}{6\pi a c^2 (1-\beta^2)^{1/2}} - \frac{e^2 \mathbf{f} \cdot \boldsymbol{\beta} \dot{f}_y}{2\pi c^4 (1-\beta^2)^2} \dots - \frac{e^2 \dot{f}_y}{6\pi c^3 (1-\beta^2)} \\
 &\quad + \frac{e^2 \ddot{f}_y a}{9\pi c^4 (1-\beta^2)^{3/2}} - \frac{e^2 \ddot{f}_y a^2}{18\pi c^5 (1-\beta^2)^2} \dots
 \end{aligned}$$

where the  $X$  axis is taken in the direction of motion, the  $Y$  axis is in any direction perpendicular to the velocity,  $a$  stands for the radius of the electron,  $f$  is its acceleration, and  $\beta = v/c$  where  $v$  is the velocity of the electron and  $c$  that of light. The charge  $e$  is expressed in Lorentz's unit. It may be remarked that the form of this equation, in so far as it involves  $\beta$ , is in exact accord with the Principle of Relativity.

The analytical reasoning involved in obtaining these results from the electrodynamic equations will be given in a paper which has been submitted for publication to the *Physical Review*.

<sup>1</sup> *Proc. Fifth Int. Cong. Math.*, **1**, 1912, (207).

<sup>2</sup> Relativity and the Ether, *Amer. J. Sci.*, *New Haven*, **38**, 1914, (169).

## ON ELECTROMAGNETIC INDUCTION AND RELATIVE MOTION. II.

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Communicated by R. A. Millikan, January 19, 1918

1. If a cylindrical condenser is placed in a uniform magnetic field with lines of induction parallel to its axis, and is short-circuited and rotated, together with the short-circuiting wire, about this axis, it becomes charged to a potential difference equal to the motional electromotive force in the wire, or the rate at which the wire cuts magnetic flux. If, however, the condenser and wire are fixed and the agent producing the magnetic field rotates, the relative motion being the same as before, the condenser does not become charged, as was proved<sup>1</sup> by precise experiment in 1912. This is the first case in electromagnetic induction in which the observed effect does not depend entirely on the relativity of the motion.

Without, however, the introduction of hypotheses unproved by experiment it does not seem possible to determine from the experiments on rotation what would happen in the case of translatory motion, or to obtain from them any answer to the question of the existence of the aether. The present investigation was undertaken with the hope of shedding some light upon these problems.

2. If an air condenser with horizontal parallel plates, short-circuited and placed in a uniform magnetic field whose lines of induction are parallel to the plates, is moved, together with the short-circuiting wire, in a direction parallel to the plates and perpendicular to the lines of induction, it will become charged to a potential difference equal to the motional electromotive force, which will be denoted by  $E$ , in the wire, the charges (provided, as will be assumed, that edge effects are negligible) being restricted to the inner or opposing faces of the plates.

3. If the region below the plane of the upper surface of the lower condenser plate were filled with a medium of zero permeability, the tubes of magnetic induction would be confined to the region above this plane, and the condenser would become charged exactly as before for the same motion.

4. If, with the arrangement of §3, the condenser and wire were to remain fixed and the agent producing the magnetic field were to move, the relative motion being the same as before, the results to be expected would be different according to the hypothesis adopted with respect to the aether:

A. If there is no aether, and the principle of relativity is valid, the condenser would become charged exactly as in §2 and 3.

B. If the aether exists, the electric intensity produced by the motion of the tubes of induction in the aether between the condenser plates would be equal and opposite to the field intensity there due to the potential differences produced by the electromotive force in the short-circuiting wire, and *there would thus be no charge on the lower condenser plate.*

Thus we should have a method of discriminating between the two hypotheses.

5. There being of course no medium of zero permeability in existence, I have tried to secure an arrangement equivalent to that of §4, so far as the effect under investigation is concerned, by using an artifice analogous to the electric guard-ring.

Two similar electromagnets, referred to as the upper and lower magnets, with their coils in series are used to produce the field. The four poles are all alike, each being a rectangular parallelepiped with the largest sides horizontal and parallel to the condenser plates. The lower magnet and condenser are fixed to the floor. The upper magnet forms the bob of a huge pendulum swung from the ceiling, and has translatory motion parallel to the condenser plates when in its lowest position. When the upper magnet is in this position, the upper and lower poles are about a centimeter apart, and the upper surface of the lower condenser plate is symmetrically located with reference to all

the poles and the other parts of the magnets. The (now) uniform field containing the condenser is conceived to be divided into two parts as follows: an approximately fixed field beneath the plane of the upper surface of the lower plate, and above this plane a field whose tubes of induction move approximately with the speed of the upper magnet. The induced electromotive forces are thus restricted to the same regions as in the imaginary experiments of §4.

6. In the experimental arrangement the lower condenser plate is (ordinarily) connected by a wire with one quadrant pair of an electrometer. The other pair and the upper plate are connected (the latter through a key at will) to a thin metallic case forming a practically complete electric screen about the condenser-electrometer system. The wire joining the condenser and electrometer can be connected to the case by closing an electrically operated key  $K$ , thus short-circuiting both condenser and electrometer. A suitable calibrating arrangement is provided.

7. The calibration experiments give the deflection  $D$  which would be produced by charging the condenser to the potential difference  $E$  of §2 (the upper plate being disconnected from the case for the purpose), insulating the lower plate and electrometer by opening  $K$ , and reconnecting the upper plate to the case.

8. The principal experiment, together with experiments for determining extraneous effects, gives the deflection  $d$  due to any charge on the lower plate produced when the upper magnet moves (with known speed) past the center of the fixed system, opening the key  $K$  at the center of the motion. An extended series of experiments shows that  $d/D$  is zero within the limits of the experimental error.

The investigation thus appears to support the hypothesis of §4, B, which assumes the existence of the aether, and to be inconsistent with the principle of relativity.

I am indebted to Mrs. Barnett for a great deal of help in making the experiments, to Mr. Freund for mechanician's assistance, and to the Carnegie Institution and Professor Pegram for some of the instruments used.

A detailed account of the work will be submitted for publication to the *Physical Review*.

<sup>1</sup> Barnett, S. J., *Physic. Rev., Ithaca, N. Y.*, **35**, 1912, (323-336)